Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft
Institut für Physik der Atmosphäre

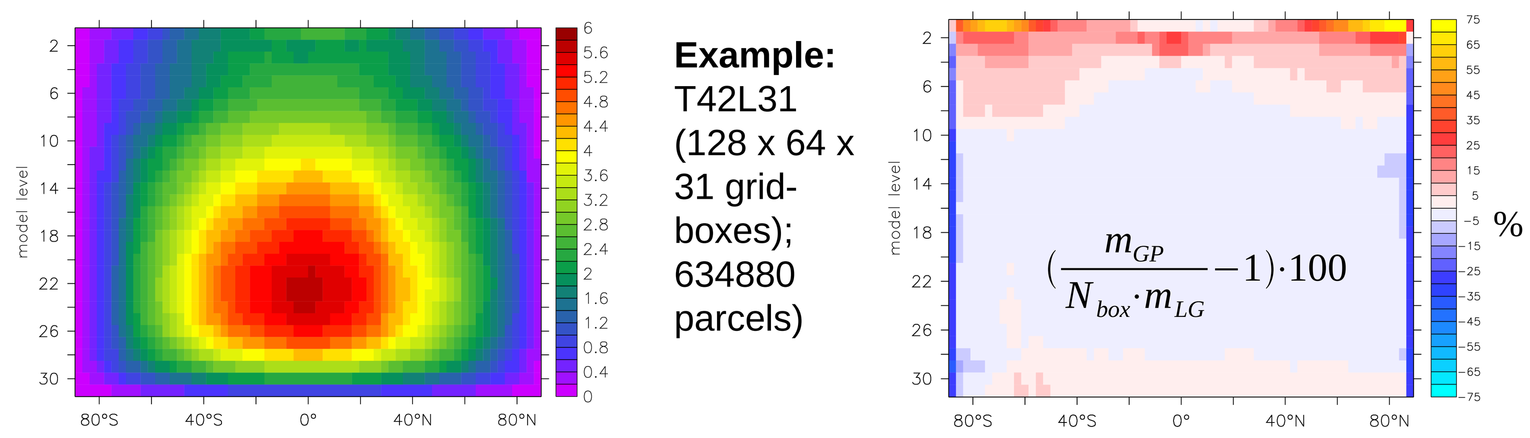
Lagrangian Transport in a Chemistry Climate Model: Methods and Applications

Patrick Jöckel, Sabine Brinkop, Volker Grewe, Robert Sausen
Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Oberpfaffenhofen, Germany
(contact: Patrick.Joeckel@dlr.de)

Abstract. The global ECHAM5/MESSy Atmospheric Chemistry (EMAC) Model is equipped with the Lagrangian transport submodel ATTILA and further corresponding Lagrangian process and diagnostic submodels. The long-term objective of this development is a full representation of atmospheric chemistry related processes in the Lagrangian frame of reference on the global scale. Furthermore, the system serves as a test-bed for new approaches, like the development of a Lagrangian dynamical climate model core. Apart from the common advantages of the Lagrangian approach (mainly mass conservation and non-diffusivity), it provides valuable additional information about spatio-temporal interrelations of atmospheric constituents, which are hardly available from Eulerian modelsWe present our methods for inter-particle diffusion, large scale and convective transport. The results shown focus on the mass exchange between the stratosphere and the troposphere, on lower stratospheric age of air spectra, and on an inter-comparison of Eulerian and Lagrangian convection and their influence on vertical tracer gradients.

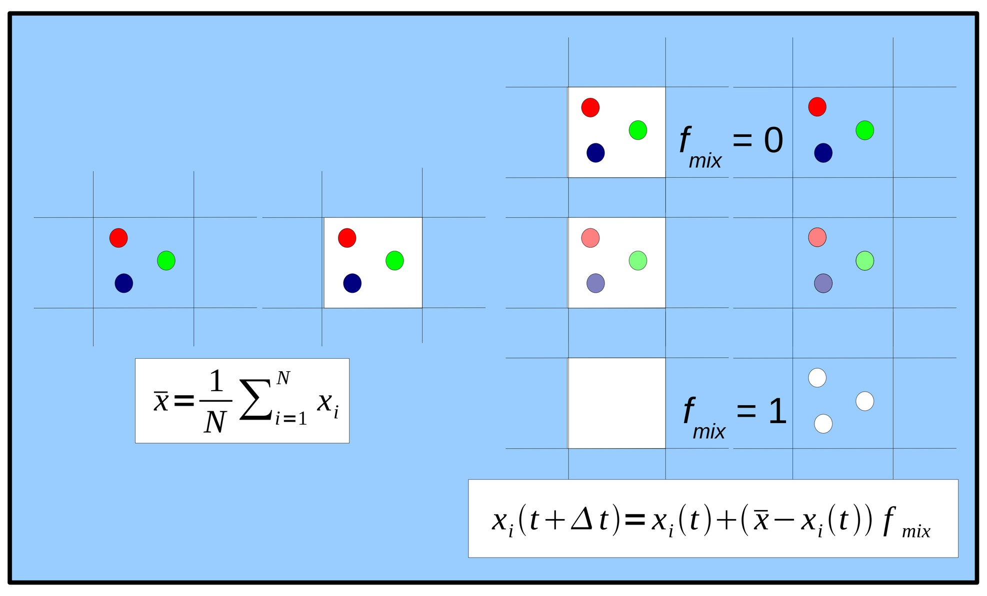
Large Scale Advection and Turbulent Diffusion in PBL (ATTILA)

- (*Reithmeier and Sausen, 2002*)
- atmosphere is divided into arbitrary number of air parcels of equal mass (m_{LG})
- random initial distribution of parcels according to air mass distribution
- parcels maintain their identity
- wind field of driving model is interpolated (horizontally bi-linear; vertically cubic Hermite) to parcel centroids
- equation of motion solved by 4th order Runge-Kutta algorithm
- random vertical displacement of particles in the planetary boundary layer (PBL)



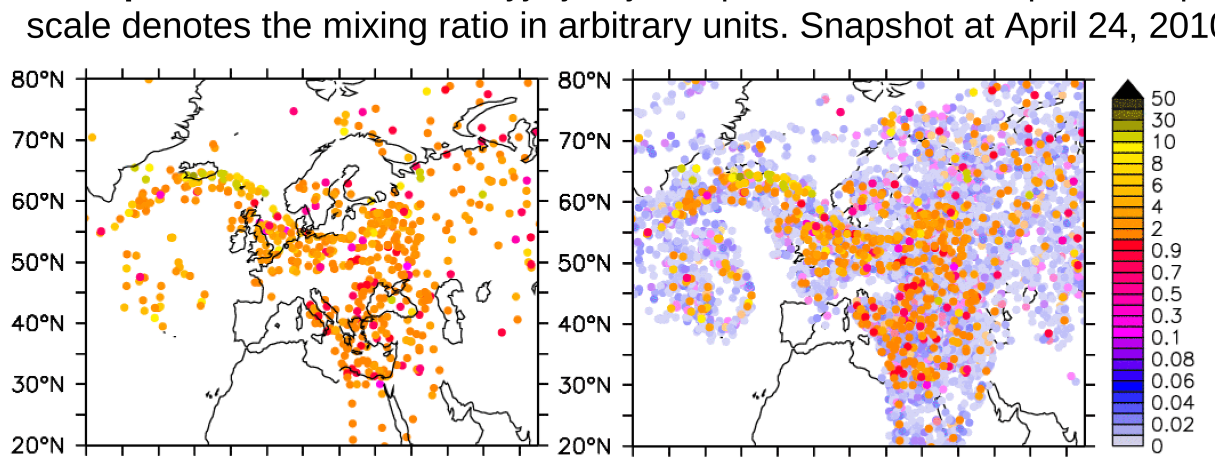
Left: Annual zonal average number of parcels (for an arbitrary year) per model grid box (N_{box}). Right: This distribution of air parcels (of mass m_{LG}) represents the mass distribution per grid cell (m_{GP}).

Inter-Parcel Exchange (LGTMIX)



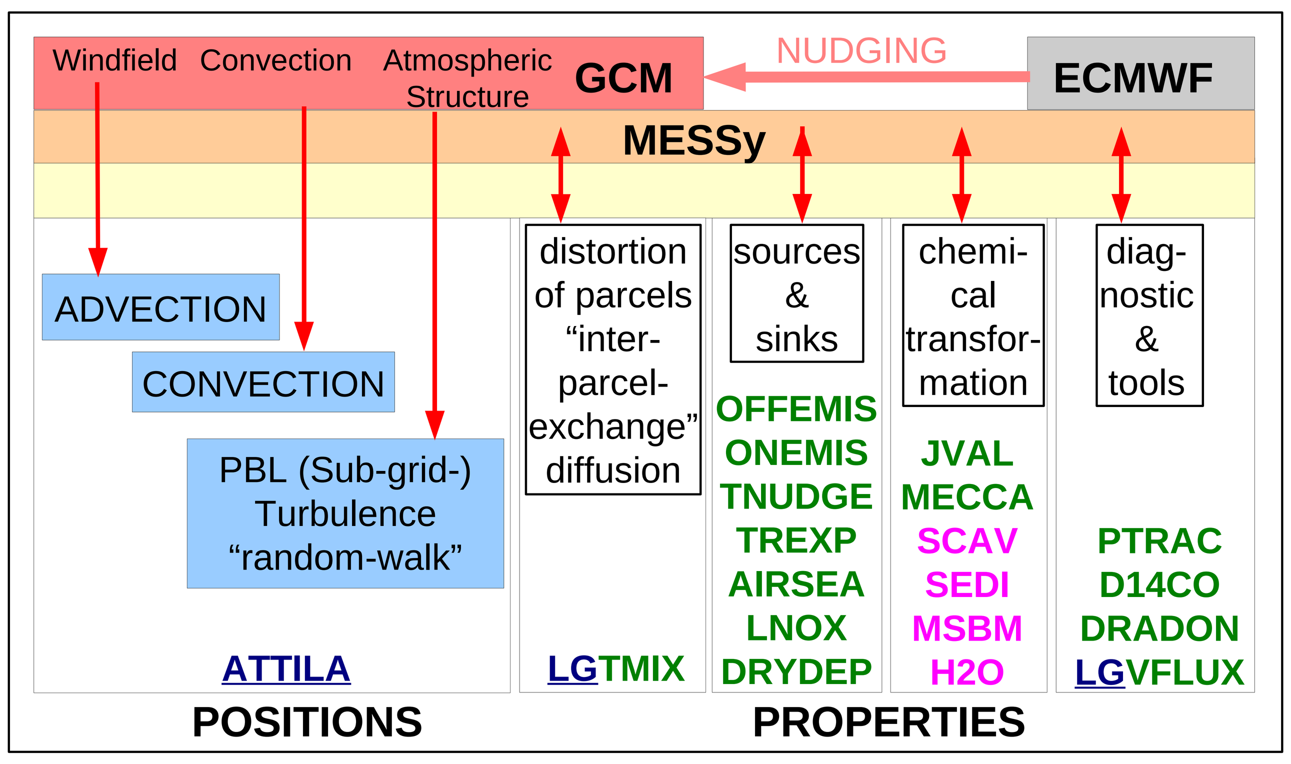
- mean field or "particle in cell " (PIC) approach with mixing parameter f_{mix}
- strictly mass conserving
- f_{mix} can either be piecewise (vertical) constant, e.g. 10^{-3} and $5\cdot10^{-4}$ in the troposphere and stratosphere, respectively; or a function of a physically meaningful model variable (TKE, CATI, etc.)

Example: Simulation of the Eyjafjallajokull plume after the eruption in April, 2010. The color scale denotes the mixing ratio in arbitrary units. Snapshot at April 24, 2010, 10:00 UTC.

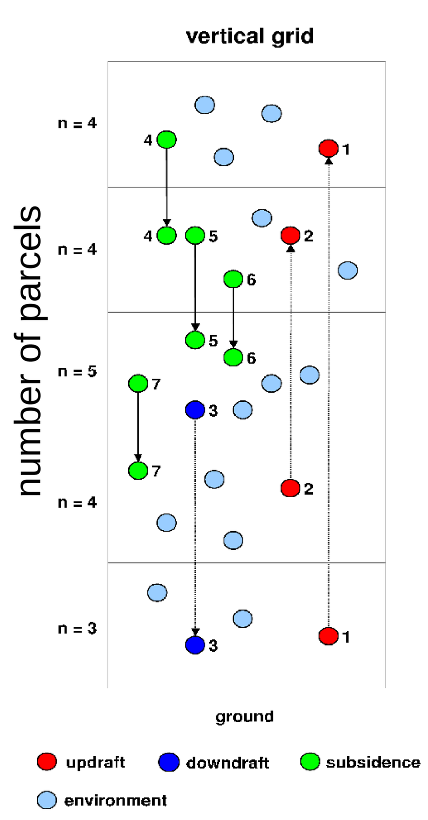


Left: Air parcels with direct source contact
Right: Air parcels with direct source contact and mixed-in volcanic plume
(T42L31, 558694)

Schematic of the Model System EMAC-LG



Convective Tracer Transport (ATTILA)



Air parcels follow the updraft, downdraft or the subsidence in the environment at a grid column with convection within one time step. The probability E of a parcel to move vertically (ascend or descend) depends on the corresponding mass-fluxes M of the Eulerian convection scheme of EMAC (*Tiedtke, 1989*). The probability E for an air parcel to follow the updraft is equal to the ratio of the mass of the air parcel moving into the updraft to the mass of air at that level. If the mass flux increases with height ($M_k - M_{k+1} > 0$), the probability is

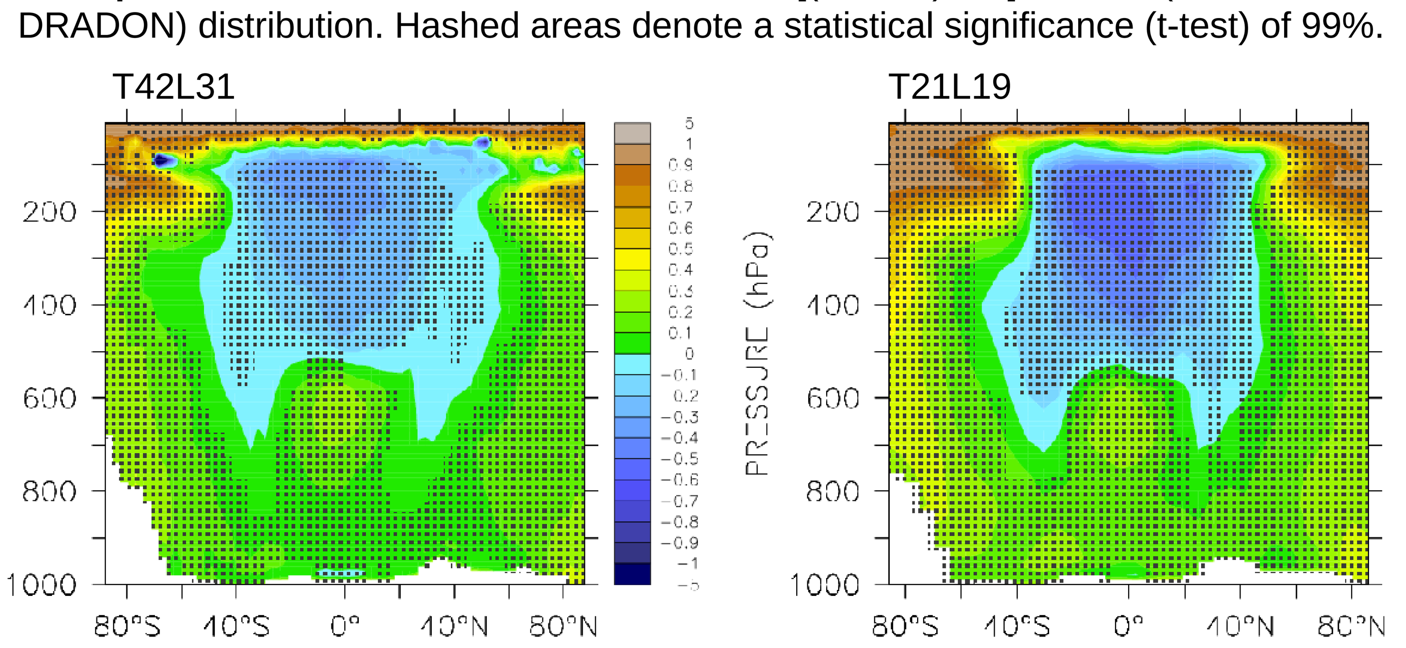
$$E_k=\frac{m_e}{m_g}=(M_k-M_{k+1})\,\Delta t\,\frac{g}{p_{k+1}-p_k}$$

with $m_g=(p_{k+1}-p_k)\frac{A}{g}$; $m_e=(M_k-M_{k+1})\,A\,\Delta t$

(p: pressure [hPa]; A: area [m^2]; M: air mass flux [$kg/m^2/s$] g: gravity acceleration [m/s^2]; Δt: time step length [s]).
If the mass flux decreases with height ($M_k - M_{k+1} < 0$), a negative probability reflects a situation where a parcel may leave the updraft due to detrainment: $E_k=\frac{(M_k-M_{k+1})}{M_{k+1}}$

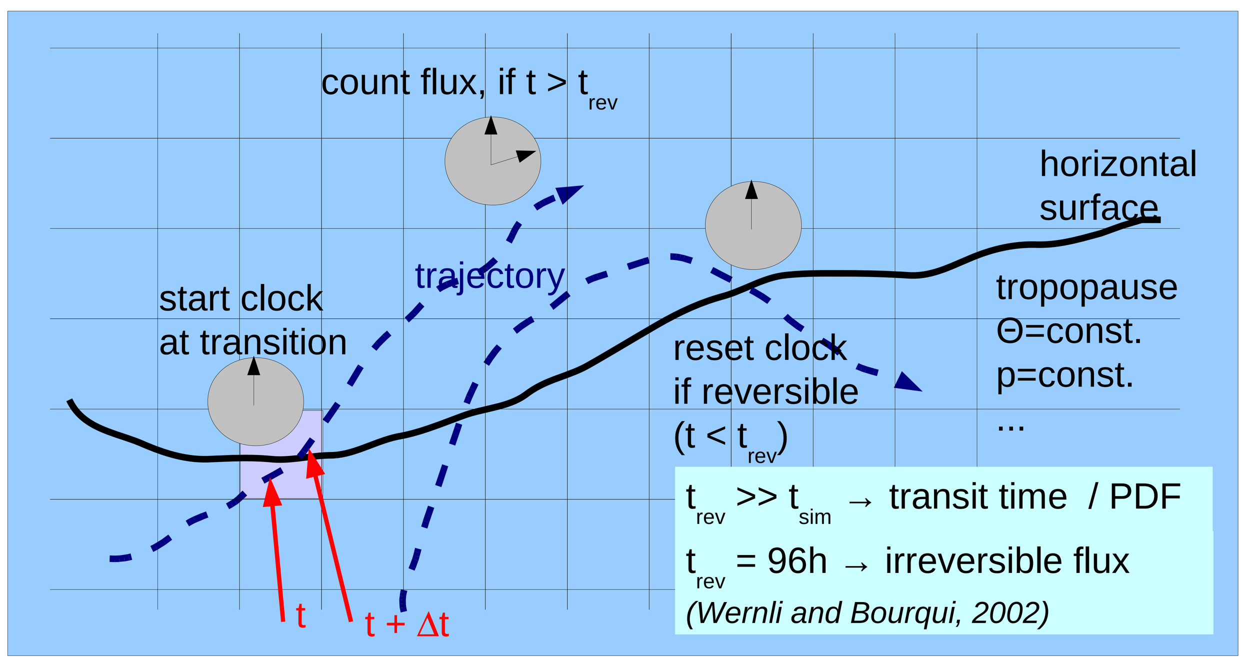
The equations of the probability functions are analogous for the downdraft.

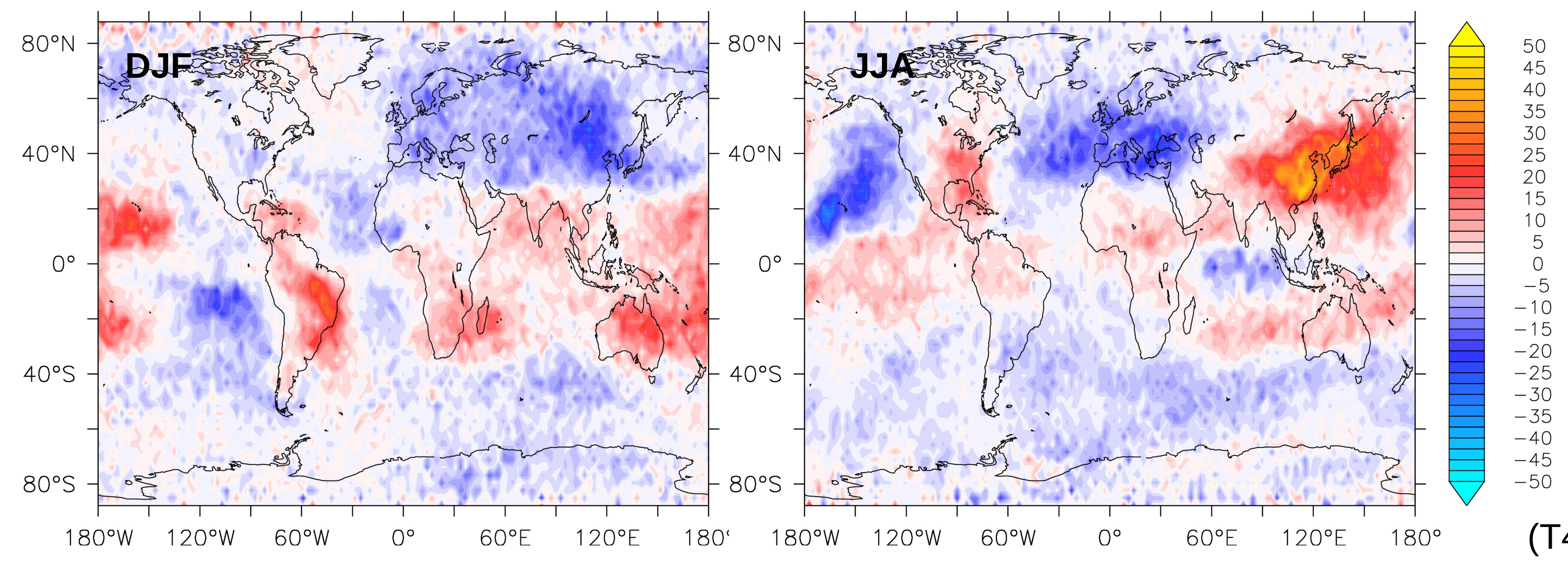
Example: Annual zonal mean relative deviation [(GP-LG)/GP] of ^{222}Rn (submodel DRADON) distribution. Hashed areas denote a statistical significance (t-test) of 99%.



The patterns are similar for both the T42L31 (634880 parcels) and the T21L19 (97280 parcels) simulation, except that the differences are larger for the coarser resolution. Note although the total number of parcels of the atmosphere differs by a factor of 6 the mean parcel number per grid box is in both setups 2.5. The region of higher values for the LG simulation, as seen in the differences of the zonal mean distribution, is attributed to the LG convection parameterisation. The differences in the polar tropopause region are an effect of the ATTILA tracer advection scheme. It is known that the GP scheme removes strong gradients of trace gases in this area (*Stenke et al., 2008*) compared to the LG scheme.

Vertical Fluxes and Transition Time Spectra (LGVFLUX)

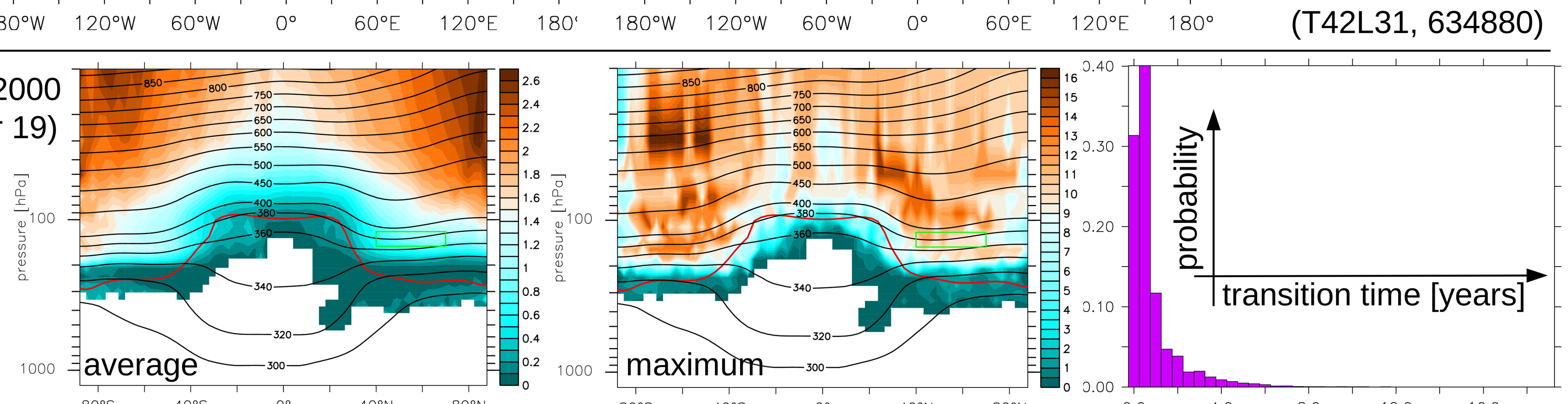




Example: Seasonally averaged flux (of air) through 100 hPa [10^{-3} kg/m²/s]

(T42L31, 634880)

Jan 2000 (year 19)



Example: Simulated (zonal) mean (left) and maximum (mid) transition time (in years) of air through 200 hPa in January 2000 (year 19 of simulation). Black contour lines denote isentropes (in K), the red line shows the tropopause. The right panel shows the corresponding transition time spectrum of air located between 40°N to 70°N and 120 and 150 hPa (as indicated by the green boxes in the left and middle panel).